L15: Entry 11 of 11 File: USPT Jun 1, 1993

DOCUMENT-IDENTIFIER: US 5216611 A
TITLE: Integrated enroute and approach guidance system for aircraft

Abstract Text (1):
Data from long range aids such as the global positioning system (GPS) and an inertial navigation system (INS) and short range aids such as a microwave landing system (MLS) are used to smoothly and automatically transition an aircraft from the long range aids to the short range aids. During cruise a Kalman filter combines data from the global positioning system and the inertial navigation system to provide accurate enroute information. When the aircraft arrives in the vicinity of the airport and begins to acquire valid data from the microwave landing system, the Kalman filter is calibrated with the MLS data to permit Precision landing with GPS/INS data alone in case the MLS system subsequently fails. In addition, navigation information begins to be derived from a weighted sum of the GPS/INS and MLS data, the weighting being determined by distance from the airport. In a first region farthest from the airport, the GPS/INS data is given a 1.0 weighting factor; and in a second region nearest the airport, the MLS data is given a 1.0 weighting factor. In a third region intermediate the first and second regions, the GPS/INS data and MLS data are proportionately and complementarily weighted as a function of the distance from the airport. If the MLS system fails, the weighting system is disabled and navigation data is again derived from the GPS/INS combination. In addition, the data from both systems are monitored, and a cockpit alarm is sounded if the data diverges beyond a specified amount.

Brief Summary Text (2):
The invention relates to new and useful improvements in aircraft navigation and airspace control systems, and more particularly to such systems using the global positioning system and the microwave landing system.

Brief Summary Text (3):
In recent years aircraft navigation and airspace control have been vastly improved by introduction of the global positioning system (GPS) and the microwave landing system (MLS). These systems supplement the existing inertial navigation systems (INS) or radionavigation systems currently used for enroute navigation, and instrument landing system (ILS) for terminal guidance. GPS uses special radio receivers in an aircraft to receive radio signals transmitted from an array of earth satellites. Using the information from the satellites, an aircraft receives and calculates its position within 50-150 feet in all three dimensions. The MLS replaces the VHF ILS with an approach and landing system using microwave signals. This provides a much more accurate and flexible landing system which permits the number of takeoff and landing operations at an airport to be sharply increased.

Brief Summary Text (4):
In the present practice, the GPS, INS and MLS systems are used separately at the discretion of the pilot, or the GPS and INS data are combined to give integrated GPS/INS enroute navigation information. The transition from GPS/IN navigation used enroute to the MLS navigation needed for landing is manual and is determined by the pilot. This transition from one navigation system to another normally occurs at a

time of high cockpit workload and navigational uncertainty and thus can decrease aircraft safety. In addition, the transition is abrupt and the flight path can be adversely affected by the differences due to errors in each device. Due to such discrete transitions, extra reliance must be placed upon ground controller vectoring, especially when combined with a specified time of arrival for spacing and sequencing. Since ground controllers are otherwise fully occupied, the extra work related to ground vectoring increases the chances of mistakes by controllers which can compromise safety. Further, each of these devices is subject to errors, and independent operation does not use one device to check the accuracy of the others.

Brief Summary Text (5):
It is therefore an object of the present invention to provide an aircraft navigation system which integrates the GPS/INS and MLS navigation systems.

Brief Summary Text (6):
It is another object of the present invention to provide an aircraft navigation system which gradually shifts between the GPS and MLS systems.

Brief Summary Text (7):
It is a further object of the present invention to provide an aircraft navigation system which minimizes errors associated with switching from the GPS/INS navigation system to the MLS navigation system.

Brief Summary Text (9):
It is yet another object of the present invention to provide an aircraft navigation system which uses the optimimum type of navigation information for each phase of an aircraft mission or flight.

Brief Summary Text (11):
It is yet an additional object of the present invention to provide a multi-source aircraft navigation system which decreases cockpit workload in critical phases of a flight and thus decreases the chances of mishap resulting from crew distraction or navigational uncertainty.

Brief Summary Text (12):
It is still another object of the present invention to provide an aircraft navigation system which minimizes the need for ground controller vectoring.

Drawing Description Text (5):
FIG. 3 is a functional block diagram of the aircraft navigation system of the present invention.

Detailed Description Text (2):
Referring first to FIG. 1, a typical integrated aircraft avionic system in which the present invention may be used is shown. The central element of the integrated avionic system is flight management system 10 which coordinates and controls the other components of the system, including a flight display system 12, a flight control system 14, a navigation sensor system 16, a communication system 18, mission avionics 20 and an air data system 22.

Detailed Description Text (3):
Data from the various systems and results generated by flight management system 10 are displayed on one or more displays comprising flight display system 12. The aircraft may be controlled by an autopilot, autothrottle and other components comprising flight control system 14. Information on aircraft position may be provided by navigation sensor system 16, which can include a wide variety of functions including GPS, inertial navigation, TACAN, VOR/ILS, MLS, automatic direction finder, and radar altimeter. Communication with airport, enroute control facilities and other aircraft is provided by a communication system 18. In the case

of military aircraft, special capabilities, including targeting radar and weapons may be provided by mission avionics 20. Finally, air data system 22 provides air mass referenced performance data used in controlling the aircraft and estimating wind and other factors which affect aircraft guidance.

Detailed Description Text (4):
Referring to FIG. 2, an operational scenario for the present invention is illustrated. An enroute aircraft 30 progresses along a flight path 31 (dotted line) comprising several segments which are related to the present invention, toward a landing on an airport runway 32 at touchdown (landings), or air release point (for cargo or personnel air drops), 34. Associated with runway, or drop zone, 32 is an MLS transmitter 36. For arrivals a cruising aircraft 30 may travel along an enroute leg 38 to a waypoint 40 using GPS, or other RNAV system, and inertial navigation system information only for navigation. At waypoint 40 aircraft 30 may travel along a transition and initial approach segment 42 to a waypoint 44 using a blend of GPS, INS, and MLS information. From waypoint 44 aircraft 30 travels along final approach segment 46 with increasing and finally total dependence on MLS information.

Detailed Description Text (5):
On departures aircraft 30 may follow a flight path 48 comprising several segments also associated with the present invention. Initially, departing aircraft 30 may travel along a takeoff segment 50 to a waypoint 52 using MLS for navigation. At a prescribed distance from the touchdown or airdrop point 52 aircraft 30 begins to use a blend of MLS, INS and GPS information to waypoint 56. At waypoint 56 aircraft 30 follows departure enroute segment 58 using GPS and INS information for navigation with decreasing weighting of MLS information.

Detailed Description Text (6):
The waypoints for both aircraft arrival and departure are arbitrarily chosen, and the use of various navigation aids may not necessarily be bounded by the waypoints. Referring now to FIG. 3, a functional block diagram of the present invention is shown. To provide context, the various elements of FIG. 3 are grouped together to relate them to flight management system 10 and flight control system 14 as shown in FIG. 1. In addition, navigation sensor system 16 is also shown in FIG. 3 to indicate the source of input data. It should be understood that certain necessary but conventional functions well known in the art, such as coordinate reference transformations, reasonableness checking and initialization, are omitted from FIG. 1 to clearly show the unique features of the invention.

Detailed Description Text (7):
The present invention uses two typical radio navigation sources, GPS and MLS, the former of which is normally used for enroute navigation and the latter for terminal area navigation. It should be understood, however, that the specific navigation systems are merely illustrative, and any other equivalent system could be used. In addition, the present invention uses INS information from the aircraft's onboard inertial navigation system, primarily for short term flight control and complementing the GPS data. Navigation sensor system 16 thus provides GPS, INS, and MLS data signals to flight management system 10 via the similarly labeled lines. The INS and GPS data signals are fed to a Kalman filter 70 whose function is to estimate inertial system errors. Kalman filters are discussed in Brown, Robert Grover, Random Signal Analysis and Kalman Filtering (John Wiley and Sons, 1983), which is incorporated herein by reference.

Detailed Description Text (12):
The composite navigation signal on line 82 is coupled via a double pole, single throw switch, or equivalent, 84 and line 86 to guidance steering device 86 in flight control system 14. Guidance steering device 86 compares the composite navigation signal on line 83 to a signal representative of the desired flight path provided by reference device 88 to provide an error estimate used to generate control signals for the aircraft flight controls. Reference device 88 describes the

desired aircraft horizontal and vertical flight path in mathematical terms, e.g., a straight line, a series of line segments or a curved path. The geometric descriptions of the flight path comprise conventional analytical expressions using latitude/longitude, ECEF (earth-centered, earth-fixed), or other suitable coordinate reference frame.

Detailed Description Text (14):
Guidance and steering device 87 describes the aircraft situation with respect to the reference flight path provided by reference device 88 in terms of positional and velocity (path vector) errors. Device 88 computes the perpendicular, horizontal and vertical distance from the reference flight path to the sensed/estimated aircraft position by taking the vector difference and converting it into scalar error quantities. Similarly, the velocity error from the reference path direction is also calculated.

Detailed Description Text (15):
The positional and velocity errors are summed and differenced with other aircraft feedback parameters, such as attitude and heading, to produce stable control signals which command the aircraft control surfaces. The control inputs cause the aircraft to modify its flight path so that the error from the reference flight path is continually corrected toward zero. There are many forms of feedback control systems well known in the art which are used to implement the guidance and steering functions. One example is described in Etkin, Bernard, Dynamics of Flight (John Wiley and Sons, 1959), which is incorporated herein by reference.

Detailed Description Text (17):
In operation, Kalman filtered GPS and INS position and velocity data are used as the primary source for navigational guidance when aircraft 30 is enroute on segment 38 of the flight path (see FIG. 2). When aircraft 30 comes into range of valid MLS signal coverage, the MLS position and velocity data are fed to Kalman filter 70 (FIG. 2) to reconcile differences between the GPS and MLS data for the airport terminal area. The Kalman filtered solution and the MLS solution are blended together in a complementary fashion and then gradually separated as a function of range, such as in the range 5 to 10 nautical miles in the present exemplary embodiment, such that only MLS data is used for the close-in terminal guidance. The reverse process occurs on the takeoff leg of a flight. This serves three purposes. First, it meets the certification criteria for precision terminal guidance using MLS only. Second, it enables the Kalman filtered solution to act as an independent performance monitor of MLS guidance, which is especially important at airports having only one MLS ground transmitter or receiver. Third, it enables switching to the Kalman filtered GPS/INS solution should the MLS become invalid. The GPS/INS solution can maintain the same accuracy as the MLS solution for a considerable time since the Kalman filtered solution is calibrated to the MLS system when the MLS signal is initially acquired. If the MLS failure occurs during the last portion of the approach, i.e., during flare and touchdown, the reversionary guidance would be sufficiently accurate and reliable to complete the maneuver. If the GPS/INS system were not calibrated, the GPS/INS solution alone would not permit a precision approach to be continued.

CLAIMS:

1. An integrated system for guiding an aircraft to a predetermined destination, which uses data generated by both a long range navigation system and a short range navigation system, comprising:

means for deriving the data from the long range navigation system;

means for deriving the data from the short range navigation system; and

automatic means for providing a weighted sum of said data from said long range

navigation system and said data from said short range navigation system, said sum being weighted as a function of the distance from a predetermined location related to one of each of said long range navigation system or said short range navigation system.

2. An integrated system for guiding an aircraft to a predetermined destination as described in claim 1 wherein said sum is weighted linearly between a first and second distance from said predetermined location.

3. An integrated system for guiding an aircraft to a predetermined destination as described in claim 2 further including means for generating aircraft control data from said data from said long range navigation system and said short range navigation system.

4. An integrated system for guiding an aircraft to a predetermined destination as described in claim 3 further including means for bypassing said providing means when valid data ceases to be derived from said short range navigation transmitter.

5. An integrated system for guiding an aircraft to a predetermined position as described in claim 4 further including:

means for detecting acquisition of valid data from said short range navigation system; and

means responsive to the detecting means for calibrating said data from said long range navigation system.

6. An integrated system for guiding an aircraft to a predetermined destination as described in claim 5 further including means for providing an alert if said data from said short range navigation system diverges from said data from said long range navigation system beyond a predetermined amount.

7. An integrated system for guiding an aircraft to a predetermined destination as described in claim 6 wherein said long range navigation system comprises an inertial navigation system onboard the aircraft and a radionavigation system external to said aircraft and further including means for combining data from the inertial guidance system and data from the radionavigation system.

8. An integrated system for guiding an aircraft to a predetermined destination as described in claim 7 wherein said combining means comprises a Kalman filter.

9. An integrated system for guiding an aircraft to a predetermined destination as described in claim 8 wherein said short range navigation system comprises a microwave landing system.

10. An integrated system for guiding an aircraft to a predetermined destination as described in claim 9 wherein said radionavigation system comprises a global positioning system.

11. An integrated system for guiding an aircraft to a predetermined destination which uses data generated by both a first navigation system having a broad coverage and a second navigation system having coverage in the vicinity of the predetermined destination, comprising:

means for deriving the data from the first navigation system;

means for deriving the data from the second navigation system;

first means for selectively gating said data from said second navigation system;

means for handling said data from said first navigation system;

means for generating a weighted sum of said data from said first navigation system and said data from said second navigation system, said weight being a function of the distance from a predetermined location related to said second navigation system;

second means for selectively gating data either from said handling means or from said generating means; and

means for generating aircraft control data from said data from said long range navigation system and said short range navigation system.

12. An integrated system for guiding an aircraft to a predetermined destination as described in claim 11 wherein said generating means comprises:

first means for weighting said data from one of either said first or said second navigation systems;

second means for weighting said data from the other of said first or said second navigation systems, said first and second weighting means having complementary weighting functions; and

means for summing weighted data from the first and second weighting means.

13. An integrated system for guiding an aircraft to a predetermined destination as described in claim 11 wherein said first selective gating means provides said data from second navigation system upon initial acquisition of valid data from said second navigation system.

14. An integrated system for guiding an aircraft to a predetermined destination as described in claim 13 wherein said second selective gating means ceases to provide data from said generating means upon loss of valid data from said second navigation system.

15. An integrated system for guiding an aircraft to a predetermined destination as described in claim 14 further including means for calibrating said data from said first navigation system upon acquisition of valid data from said second navigation system.

16. An integrated system for guiding an aircraft to a predetermined destination as described in claim 15 wherein said means for deriving said data from said first navigation system includes a Kalman filter.

17. An integrated system for guiding an aircraft to a predetermined destination as described in claim 16 wherein said first navigation system comprises an inertial navigation system onboard the aircraft and a radionavigation system external to said aircraft and further including means for deriving said data from said first navigation system.

18. An integrated system for guiding an aircraft to a predetermined destination as described in claim 17 wherein said second navigation system comprises a microwave landing system.

19. An integrated system for guiding an aircraft to a predetermined destination as described in claim 18 wherein said radionavigation system comprises a global positioning system.

20. An integrated system for guiding an aircraft to an airport, which uses data generated by an inertial navigation system, a global positioning system and a

microwave landing system, comprising:

means for deriving the data from the inertial navigation system;

means for deriving the data from the global positioning system;

means for combining said data from said inertial navigation system and said global positioning system to provide composite navigation data;

means for deriving the data from the microwave landing system;

first means for weighting either one of said composite data or said microwave landing system data;

second means for weighting the other of the other of said composite data or said microwave landing system data, said first and second weighting means having complementary weighting functions;

said weighting being a function of the distance from a predetermined location related to one of said global positioning system or said microwave landing system;

means for summing data from the first and second weighting means;

first means for selectively gating said microwave landing system data to said second weighting means and said combining means;

second means for selectively gating data either from said combining means or from said summing means; and

means for generating aircraft control data from the data from said data gated by the second gating means.

21. An integrated system for guiding an aircraft to an airport as described in claim 20 wherein said combining means comprises a Kalman filter.

22. An integrated system for guiding an aircraft to an airport as described in claim 21 wherein said first gating means begins gating said microwave landing system when valid microwave landing system data is received.

23. An integrated system for guiding an aircraft to an airport as described in claim 22 further including means for calibrating said Kalman filter when said microwave landing system data is initially gated by said first gating means.

24. An integrated system for guiding an aircraft to an airport as described in claim 23 wherein said second gating means ceases to gate data when valid microwave landing system data ceases to be received.

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DOCUMENT-IDENTIFIER: US 20040073360 A1
TITLE: Tracking, auto-calibration, and map-building system

Summary of Invention Paragraph:
[0135] The estimation subsystem includes an auto-calibration filter.

Summary of Invention Paragraph:
[0136] The estimation subsystem includes a simultaneous localization and auto-calibration filter.

Detail Description Paragraph:
[0165] The terms "environment" and "galaxy" is used interchangeably in the description below. The environment can be one, two, or three dimensional. For example, environment 106 may be a track that winds through a factory. Environment 106 may be a land mass, an ocean floor, a factory floor, a room, a building, a town, an airspace, an ocean body, or an underground tunnel. Environment 106 may be moving relative to earth. For example, the environment may be the interior of an aircraft carrier or a space surrounding a space shuttle orbiting the earth. Vehicle 100 may be, for example, a land vehicle, a water vehicle, an aircraft, a spacecraft, a robot, a person, a part of a person, a flying object, a floating object, an underwater moving object, an animal, a camera, a weapon, a handheld object, a sensing apparatus, a helmet, a tool, a medical instrument, a display, a piece of sports equipment, a shoe, a boot, an article of clothing, a personal protective equipment, or some other object. The terms vehicle and navigation are used for simplicity, but should not be construed to limit the scope of the invention, which is equally intended for tracking any object for any purpose. Therefore, the terms "navigation system" and "tracking system" will be used interchangeably in the description below, as will the terms "vehicle" and "tracked object".

Detail Description Paragraph:
[0166] The pose of the vehicle is estimated in a fixed frame of reference in environment 106, which is referred to as the galaxy frame of reference or the navigation frame of reference ("N-frame"). In one version of the system, the galaxy frame of reference is an inertial frame of reference. Inertial sensors 104, which are part of an inertial measurement unit (IMU), provide measurements for inertial tracking of the vehicle by an inertial navigation subsystem.